

# Four-Fermi Effective Operators at $e^+e^- \rightarrow t\bar{t}$ <sup>1</sup>

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## Abstract

The process of top quark pair production at Next Linear Collider (NLC) has been considered adopting an effective Lagrangian approach and including all operators of dim 6 which can be tree-level-generated within unknown underlying theory. All contributing helicity amplitudes are presented. It has been found that four-fermion operators can provide the leading non-standard contribution to the total cross section. Expected statistical significance of the non-standard signal for the total cross section and forward-backward asymmetry have been calculated taking into account existing experimental constraints. It has been shown that adopting realistic luminosity of NLC and conservative efficiency for the top-quark pair detection, the total cross section may be sensitive to non-standard physics of an energy scale around  $\Lambda = 5$  TeV.

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# 1 Introduction

Linear high-energy  $e^+e^-$  collider can prove to be very useful laboratory to study physics of the top quark. In spite of spectacular successes of experimental high-energy physics (e.g. precision tests of the Standard Model) the interactions of the recently discovered [1] top quark are still unknown. There is no evidence that the top quark interactions obey the scheme provided by the Standard Model (SM) of electroweak interactions. The aim of this letter is to look for non-standard physics effects in the process  $e^+e^- \rightarrow \bar{t}t$ . We will show that the present knowledge of the electroweak physics allows for large beyond the SM corrections to the top quark production at NLC. There exist already a large literature [2] devoted to non-standard effects in the top-quark physics, however authors restricts their research to corrections to the  $\bar{t}tZ$  and/or  $\bar{t}t\gamma$ . There is however no reason to neglect four-Fermi operators which may also influence the top quark production process  $e^+e^- \rightarrow \bar{t}t$  at NLC. This is a subject of the presented research.

We shall follow here a model independent approach where all possible non-standard effects are parameterized by means of an effective Lagrangian [3, 4]. This formalism is model and process independent and thus provides an unprejudiced analysis of the data. We will parameterize all non-standard effects using the coefficients of a set of effective operators (which respect the symmetries of the SM). These operators are chosen so that there are no *a-priori* reasons to suppose that the said coefficients are suppressed.

The effective Lagrangian approach requires a choice of the low energy particle content. In this paper we will assume that the SM correctly describes all such excitations. Thus we imagine that there is a scale  $\Lambda$ , independent of the Fermi scale, at which the new physics becomes apparent. Since the SM is renormalizable and the new physics is assumed to be heavy due to a large dimensional parameter  $\Lambda$ , the decoupling theorem [5] is applicable and requires that all new physics effects be suppressed by inverse powers of  $\Lambda$ . All such effects are expressed in terms of a series of local *gauge invariant* operators of canonical dimension  $> 4$ ; the catalogue of such operators up to dimension 6 is given in Ref. [6] (there are no dimension 5 operators respecting the global and local symmetries of the SM).

For the situation we are considering it is natural to assume that the underlying theory is weakly coupled. *Thus the relevant property of a given dimension 6 operator is whether it can be generated at tree level by the underlying physics.* The coefficient of such operators are expected to be  $O(1)$ ; in contrast, the coefficients of loop-generated operators will contain a suppression<sup>3</sup> factor  $\sim 1/16\pi^2$ . The determination of those operators which are tree-level-generated is given in Ref. [7].

Here, we shall restrict ourself to effects produced by those operators which can be tree-level-generated and therefore coefficients of such operators are not *a-priori* suppressed. In this respect the present analysis differs from others appearing in the literature [8] which concentrate on one-loop-generated operators related to the vector-boson self interactions. (drawbacks of those analysis have been emphasized in Ref. [4]).

The strategy which we follow in this paper is to develop the effects of the tree-level-generated operators contributing to  $\bar{t}t$  production at  $e^+e^-$  collisions. We will consider the constraints implied by current high-precision data and predict the sensitivity to new effects at proposed version of NLC.

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<sup>3</sup>If there is a large number of loop graphs this suppression factor can be reduced.

## 2 The Effective Lagrangian

Hereafter we will adopt a notation from the Büchmüller and Wyler classical paper, see Ref. [6]. The tree-level-generated operators which will directly contribute to  $e^+e^- \rightarrow \bar{t}t$  are the following

$$\begin{aligned}\mathcal{O}_{lq}^{(1)} &= (\bar{l}\gamma_\mu l) (\bar{q}\gamma^\mu q) & \mathcal{O}_{lq}^{(3)} &= (\bar{l}\gamma_\mu \tau^I l) (\bar{q}\gamma^\mu \tau^I q) \\ \mathcal{O}_{eu} &= (\bar{e}\gamma_\mu e) (\bar{u}\gamma^\mu u) & \mathcal{O}_{lu} &= (\bar{l}u) (\bar{u}l) \\ \mathcal{O}_{qe} &= (\bar{q}e) (\bar{e}q) & \mathcal{O}_{qde} &= (\bar{l}e) (\bar{d}q) \\ \mathcal{O}_{lq} &= (\bar{l}e) \epsilon (\bar{q}u) & \mathcal{O}_{lq'} &= (\bar{l}u) \epsilon (\bar{q}e).\end{aligned}\tag{1}$$

The tree-level-generated operators which modify  $\bar{t}tZ$  and  $\bar{t}t\gamma$  vertices are

$$\begin{aligned}\mathcal{O}_{\phi q}^{(1)} &= i (\phi^\dagger D_\mu \phi) (\bar{q}\gamma^\mu q) & \mathcal{O}_{\phi l}^{(3)} &= i (\phi^\dagger \tau^I D_\mu \phi) (\bar{q}\tau^I \gamma^\mu q) \\ \mathcal{O}_{\phi u} &= i (\phi^\dagger D_\mu \phi) (\bar{u}\gamma^\mu u).\end{aligned}\tag{2}$$

The above operators would effect the SM  $\bar{t}tZ$  and  $\bar{t}t\gamma$  vertices and modify the amplitude for  $e^+e^- \rightarrow \bar{t}t$  by the s-channel Z and  $\gamma$  exchange.

Since we are restricting ourself to tree-level-generated operators, only vector and axial form-factors for  $\bar{t}tZ$  and  $\bar{t}t\gamma$  vertices could receive any corrections. Therefore we may parameterize those vertices as :

$$\Gamma_\mu^i = \frac{g}{2} \bar{t} \gamma_\mu (A^i - B^i \gamma_5) t,\tag{3}$$

where  $i = \gamma, Z$ .  $A^i$  and  $B^i$  can be written as a sum of the SM ( $A_{SM}^i, B_{SM}^i$ ) and non-standard ( $\delta A^i, \delta B^i$ ) contributions:

$$\begin{aligned}A_{SM}^\gamma &= \frac{4}{3} \sin \theta_W & A_{SM}^Z &= \frac{1}{\cos \theta_W} \left( \frac{1}{2} - \frac{4}{3} \sin^2 \theta_W \right) \\ B_{SM}^\gamma &= 0 & B_{SM}^Z &= \frac{1}{2 \cos \theta_W} \\ \delta A^\gamma &= 0 & \delta A^Z &= \frac{1}{2 \cos \theta_W} \left( -\alpha_{\phi q}^{(1)} + \alpha_{\phi q}^{(3)} - \alpha_{\phi u} \right) \frac{v^2}{\Lambda^2} \\ \delta B^\gamma &= 0 & \delta B^Z &= \frac{1}{2 \cos \theta_W} \left( -\alpha_{\phi q}^{(1)} + \alpha_{\phi q}^{(3)} + \alpha_{\phi u} \right) \frac{v^2}{\Lambda^2},\end{aligned}\tag{4}$$

where  $\theta_W$  is the Weinberg angle and  $v = 246$  GeV.

The input parameters we are using are  $G_F$ ,  $M_Z$  and  $\alpha_{QED}$ . There are tree-level-generated operators which enter our calculations only through corrections to the input parameters:

$$\begin{aligned}\mathcal{O}_\phi^{(1)} &= (\phi^\dagger \phi) [(D_\mu \phi)^\dagger D^\mu \phi] & \mathcal{O}_\phi^{(3)} &= (\phi^\dagger D_\mu \phi) [(D_\mu \phi)^\dagger \phi] \\ \mathcal{O}_l^{(3)} &= (\bar{l} \tau^I \gamma_\mu l) (\bar{l} \tau^I \gamma^\mu l) & \mathcal{O}_{\phi l}^{(3)} &= i (\phi^\dagger \tau^I D_\mu \phi) (\bar{l} \tau^I \gamma^\mu l).\end{aligned}\tag{5}$$

Explicit corrections to  $G_F$ ,  $M_Z$  and  $\alpha_{QED}$  can be obtained from Ref. [6].

The complete list of tree-level-generated operators may be found in Ref. [7]. *The effects of those operators present the widest window into physics beyond the SM.*

Given the above list the Lagrangian which we will use in the following calculations is

$$\mathcal{L} = \mathcal{L}^{SM} + \frac{1}{\Lambda^2} \sum_i \{ \alpha_i \mathcal{O}_i + \text{h.c.} \}\tag{6}$$

It would be more useful to rewrite (after some necessary Fiertz transformation) the above four-Fermi operators (1) in the following way:

$$\begin{aligned} \mathcal{L}^{4-Fermi} = & \sum_{i,j=L,R} [S_{ij} (\bar{e} P_i e) (\bar{t} P_j t) + V_{ij} (\bar{e} \gamma_\mu P_i e) (\bar{t} \gamma^\mu P_j t) + \\ & T_{ij} \left( \bar{e} \frac{\sigma_{\mu\nu}}{\sqrt{2}} P_i e \right) \left( \bar{t} \frac{\sigma^{\mu\nu}}{\sqrt{2}} P_j t \right) ], \end{aligned} \quad (7)$$

where  $P_{L,R} = 1/2(1 \mp \gamma_5)$ . The following constraints must be satisfied by the coefficients:

$$S_{LL} = S_{RR}^* \quad V_{ij} = V_{ij}^* \quad T_{LL} = T_{RR}^* \quad T_{LR} = T_{RL} = 0 \quad (8)$$

From the gauge invariance of the Lagrangian it follows that  $S_{LR} = S_{RL} = 0$ . All  $S_{ij}$ ,  $V_{ij}$  and  $T_{ij}$  could be expressed in terms of the initial  $\alpha$ 's from the four-Fermi part of the Lagrangian (6).

Apart of the common factor  $2iE$ , where  $E$  is the beam energy, with  $s = 4E^2$ ,  $k = E\sqrt{1 - 4m_t^2/s}$  and  $\theta$  defined as an angle between outgoing top and incoming electron, helicity amplitudes for  $e^+e^- \rightarrow t\bar{t}$  emerging from scalar and tensor type operators read as follows:

$$\begin{aligned} (- - - -) &= (E - k)(S_{LL} + 2T_{LL} \cos \theta) - S_{LR}(E + k) \\ (- - - +) &= +2T_{LL}m_t \sin \theta \\ (- - + -) &= +2T_{LL}m_t \sin \theta \\ (- - ++ ) &= (E + k)(S_{LL} - 2T_{LL} \cos \theta) - S_{LR}(E - k) \\ (+ + - -) &= (E + k)(S_{RR} - 2T_{RR} \cos \theta) - S_{RL}(E - k) \\ (+ + - +) &= -2T_{RR}m_t \sin \theta \\ (+ + + -) &= -2T_{RR}m_t \sin \theta \\ (+ + ++ ) &= (E - k)(S_{RR} + 2T_{RR} \cos \theta) - S_{RL}(E + k), \end{aligned} \quad (9)$$

where helicities of  $e^-$ ,  $e^+$ ,  $t$  and  $\bar{t}$  are indicated in the parenthesis. For the top quark we use  $m_t = 174$  GeV. Vector type operators produce the following amplitudes:

$$\begin{aligned} (- + - -) &= -(V_{LR} + V_{LL})m_t \sin \theta \\ (- + - +) &= +[E(V_{LR} + V_{LL}) + k(V_{LL} - V_{LR})](1 + \cos \theta) \\ (- + + -) &= -[E(V_{LR} + V_{LL}) - k(V_{LL} - V_{LR})](1 - \cos \theta) \\ (- + ++ ) &= +(V_{LR} + V_{LL})m_t \sin \theta \\ (+ - - -) &= -(V_{RL} + V_{RR})m_t \sin \theta \\ (+ - - +) &= -[E(V_{RL} + V_{RR}) - k(V_{RR} - V_{RL})](1 - \cos \theta) \\ (+ - + -) &= +[E(V_{RL} + V_{RR}) + k(V_{RR} - V_{RL})](1 + \cos \theta) \\ (+ - ++ ) &= +(V_{RL} + V_{RR})m_t \sin \theta. \end{aligned} \quad (10)$$

Since the  $\gamma$  and  $Z$  exchange leads to helicity amplitudes of the same form as those above, therefore we will use them to describe SM, vertex and vector four-Fermi operator effects. Adopting for a notation  $S \equiv S_{RR}$  and  $T \equiv T_{RR}$  we obtain the following contributions to the differential cross sections from scalar-tensor and vector operators, respectively:

$$\begin{aligned} \frac{d\sigma^{ST}}{d\cos\theta} &= \frac{N_C\beta_t}{32\pi} [8|T|^2k^2 \cos^2 \theta - 8\text{Re}(ST^*)Ek \cos \theta + |S|^2(2E^2 - m_t^2) + 4|T|^2m_t^2], \\ \frac{d\sigma^{VV}}{d\cos\theta} &= \frac{N_C\beta_t s}{256\pi} [ (|A_L|^2 + |A_R|^2 + |B_L|^2 + |B_R|^2) \beta_t^2 \cos^2 \theta + \\ & 4(\text{Re}(A_L B_L^*) - \text{Re}(A_R B_R^*)) \beta_t \cos \theta + \\ & 2(|A_L|^2 + |A_R|^2) - \beta_t^2 (|A_L|^2 + |A_R|^2 - |B_L|^2 - |B_R|^2) ], \end{aligned} \quad (11)$$

where  $N_C$  is a number of colours and  $\beta_t = \frac{2}{\sqrt{s}}k$ . Above we used the following, more convenient notation:

$$\begin{aligned} A_L &= V_{LL} + V_{LR} & A_R &= V_{RL} + V_{RR} \\ B_L &= V_{LL} - V_{LR} & B_R &= V_{RL} - V_{RR}. \end{aligned} \quad (12)$$

One should notice that besides the SM  $Z$  and  $\gamma$  exchange there are two sorts of contributions to  $A_{L,R}$  and  $B_{L,R}$ : these which enter as vertex corrections to the  $\bar{t}tZ$  and  $\bar{t}t\gamma$  couplings (denoted as  $A_{L,R}^{\gamma,Z}$  and  $B_{L,R}^{\gamma,Z}$ ) and those which emerge directly from vector type four-Fermi operators (denoted by  $A_{L,R}^V$  and  $B_{L,R}^V$ ). The former are generated by operators (2) once the latter ones by operators (1). *It should be noticed that  $A_{L,R}^{\gamma,Z}$  and  $B_{L,R}^{\gamma,Z}$  are suppressed by the  $Z$  and/or  $\gamma$  propagators whereas  $A_{L,R}^V$  and  $B_{L,R}^V$  are suppressed by the constant scale of new physics  $\Lambda$ . This is why we should expect that at sufficiently high energy vector type corrections shell dominate over vertex ones.*

Since an approximation  $m_b = 0$  have been adopted, there is no interference between scalar-tensor and vector operators. However the SM contributions to the amplitude do interfere with vector-type four-Fermi operators and those which modify  $\bar{t}tZ$  and  $\bar{t}t\gamma$  vertices. Although scalar-tensor operators do not interfere with the SM contributions their effects are very relevant for sufficiently large CM energy since the coefficients  $S_{ij}$ ,  $T_{ij}$  could be even of the order of  $\frac{1}{\Lambda^2}$ .

### 3 Experimental and Theoretical Constraints

Coefficients of some of the relevant operators are restricted either by experimental constraints or by theoretical requirements of naturality.  $\alpha_{\phi l}^{(3)}$ , coefficient of the operator  $\mathcal{O}_{\phi l}^{(3)}$  (which enters our calculations through corrections to the Fermi constant) is already restricted by LEP data [9], which at the  $3\sigma$  level imply the following constraints [10]:

$$\Lambda_{TeV} \gtrsim 2.5 \sqrt{|\alpha_{\phi l}^{(3)}|} \quad (13)$$

where  $\Lambda_{TeV}$  is the scale of new physics in TeV units.

Similarly the contributions to the oblique parameter  $\mathbf{T}$  [11] arise from  $\mathcal{O}_{\phi}^{(3)}$ , explicitly

$$|\delta\mathbf{T}| = \frac{4\pi}{\sin^2\theta_W} |\alpha_{\phi}^{(3)}| \frac{v^2}{\Lambda^2} \lesssim 0.4 \quad (14)$$

This bound [12] implies  $\Lambda_{TeV} \gtrsim 1.7 \sqrt{|\alpha_{\phi}^{(3)}|}$  (at  $3\sigma$ ).

However,  $\alpha_{\phi}^{(3)}$  and  $\alpha_{\phi}^{(1)}$ <sup>4</sup> both contributing to corrections to our input parameters are experimentally unconstrained.

It is easy to notice that scalar and tensor type four-Fermi operators emerging after applying Fiertz transformation to  $\mathcal{O}_{lq}$  and  $\mathcal{O}_{lq'}$  would contribute at the one-loop level to the electron mass and anomalous magnetic moment of the electron:

$$\delta m_e^S \sim m_t S \frac{m_t^2}{\Lambda^2} \quad \delta a_e^T \sim T \frac{m_e m_t}{\Lambda^2}. \quad (15)$$

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<sup>4</sup>None of the high precision measurements constrain  $\alpha_{\phi}^{(1)}$  since, without direct observation of the Higgs, the tree-level effects of this operator are absorbed in the wave function renormalization of the scalar doublet.

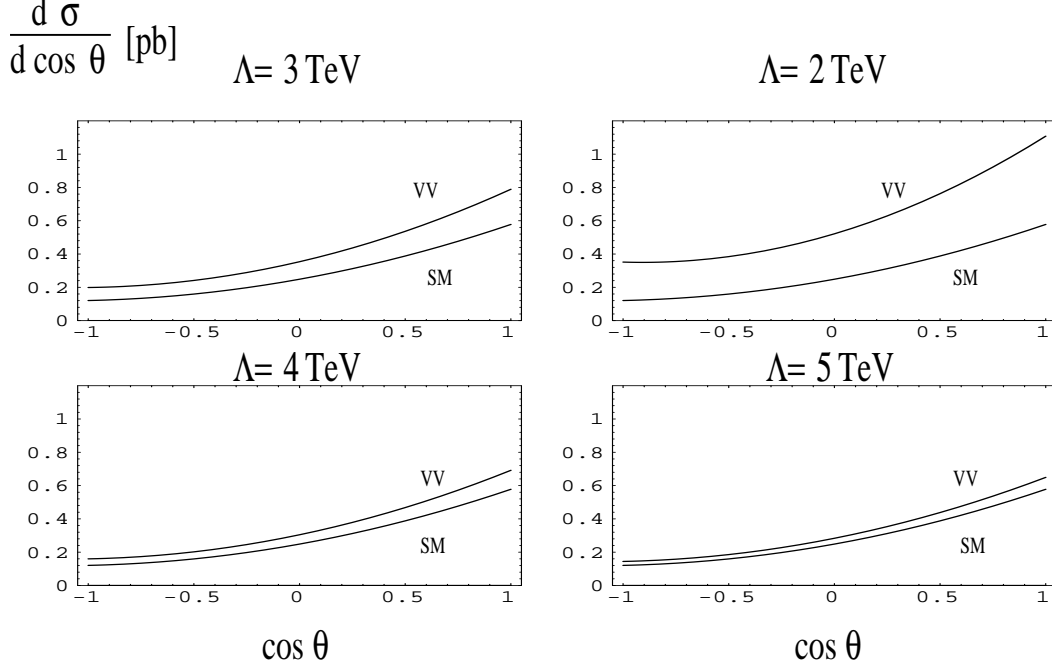


Figure 1: The differential cross section  $\frac{d\sigma}{d\cos\theta}$  as a function of  $\cos\theta$  for  $s = .5^2 \text{ TeV}^2$  for  $\Lambda = 2, 3, 4, 5 \text{ TeV}$ .  $VV$  and  $SM$  denote the prediction with and without vector-type four-Fermi operators, respectively.

Although, one can imagine some mechanisms to cancel above contributions, preserving non-zero  $S$  and  $T$ , however here, presenting numerical results we will assume  $S = T = 0$  to avoid any fine-tuning necessary to overcome the above constraints.

## 4 Results and Perspectives

We focus here on two observables, the total cross section  $\sigma_{tot}$  and  $\mathcal{A}_{FB}$  for  $e^+e^- \rightarrow \bar{t}t$ . However, it is instructive first to look at a differential cross section  $\frac{d\sigma}{d\cos\theta}$  presented in the Fig. 1. Since we would like to emphasize the effects of four-Fermi operators, in numerical calculations we assumed always  $S = T = A_{L,R}^{\gamma,Z} = B_{L,R}^{\gamma,Z} = 0$  and  $A_{L,R}^V = B_{L,R}^V = -1/\Lambda^2$ , also corrections to  $G_F$ ,  $m_Z$  and  $\alpha_{QED}$  are suppressed for this purpose. Although corrections to the  $\frac{d\sigma}{d\cos\theta}$  can be substantial (even 100% for  $\Lambda = 2 \text{ TeV}$ ), however it is seen that the main effect consist of rescaling the angular distribution.

The total cross section  $\sigma_{tot}$  as a function of the center of mass energy is shown in Fig. 2. As we have already anticipated the corrections are rising with energy what is an effect of relative enhancement of four-Fermi interactions.

There are two quantities relevant for experimental potential of NLC, namely the total integrated luminosity  $L$  and the tagging efficiency for an observation of  $\bar{t}t$  pairs  $\varepsilon_{tt}$ . Since they both enter the statistical significance in a combination  $\sqrt{\varepsilon_{tt}L}$  it will useful to adopt a notation  $\varepsilon_L \equiv \sqrt{\varepsilon_{tt}L}$  and parameterize our results in terms of  $\varepsilon_L$ . Below we present a table showing  $\varepsilon_{tt}$  and  $L$  corresponding to  $\varepsilon_L = 30, 50, 100 \text{ pb}^{-1/2}$ .

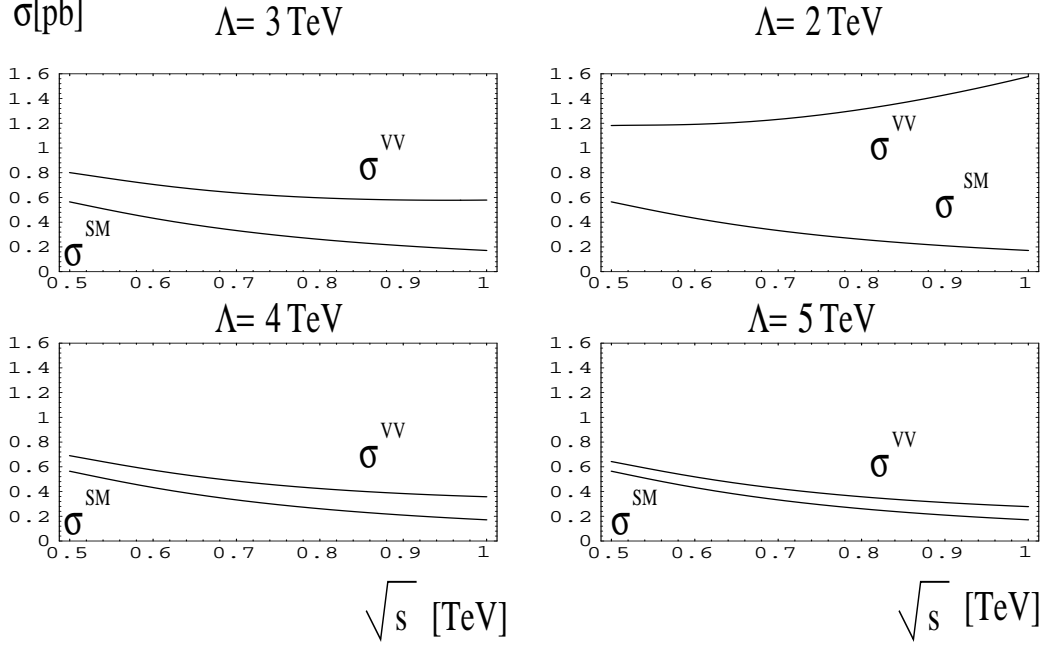


Figure 2: The total cross section  $\sigma_{tot}$  as a function of the CM energy for  $\Lambda = 2, 3, 4, 5$  TeV.  $VV$  and  $SM$  denote the prediction with and without vector-type four-Fermi operators, respectively.

$L[10^4 \text{ pb}^{-1}]$	1.	2.	3.	4.	5.
$\varepsilon_{tt}(\text{for } \varepsilon_L = 30 \text{ pb}^{-1/2})$	.09	.05	.03	.02	.02
$\varepsilon_{tt}(\text{for } \varepsilon_L = 50 \text{ pb}^{-1/2})$	.25	.13	.08	.06	.02
$\varepsilon_{tt}(\text{for } \varepsilon_L = 100 \text{ pb}^{-1/2})$	1.0	.50	.33	.25	.20

Since  $L = 2 \times 10^4 \text{ pb}^{-1}$  looks presently as realistic yearly available luminosity, we can see from the above table that  $\varepsilon_L = 50 \text{ pb}^{-1/2}$  would require only 13% for  $\bar{t}t$  tagging efficiency  $\varepsilon_{tt}$ . Some rough estimations of the efficiency are available in the literature [13] for the most frequent final state topologies: 6 jets ( $BR \sim 50\%$ ) and 4 jets + 1 charged lepton ( $BR \sim 40\%$ ). For the 6 jet channel  $\varepsilon_{tt}$  is expected to be around 30%, whereas for 4 jet + 1 lepton 15% should be obtained. Therefore we can conclude that already  $\varepsilon_L = 50 \text{ pb}^{-1/2}$  can serve as a realistic estimation of the detection potential of the NLC.

The quantity which provides the relevant for us information is the statistical significance of the non-standard physics effects in  $e^+e^- \rightarrow \bar{t}t$ . For the total cross section  $\sigma_{tot}$  statistical significance is given by the following formula:

$$N_{SD}^\sigma = \varepsilon_L \frac{\sigma_{tot} - \sigma_{tot}^{SM}}{\sqrt{\sigma_{tot}}}, \quad (16)$$

where  $\sigma_{tot} \equiv \sigma^{ST} + \sigma^{VV}$ . For the forward backward asymmetry we obtain:

$$N_{SD}^{FB} = \frac{\mathcal{A}_{FB} - \mathcal{A}_{FB}^{SM}}{\sqrt{1 - \mathcal{A}_{FB}^2}} \sqrt{\sigma_{tot}} \varepsilon_L. \quad (17)$$

We must remember that we are not allowed to trust our lowest order effective Lagrangian calculation whenever relative corrections are greater than, say 10%, therefore it

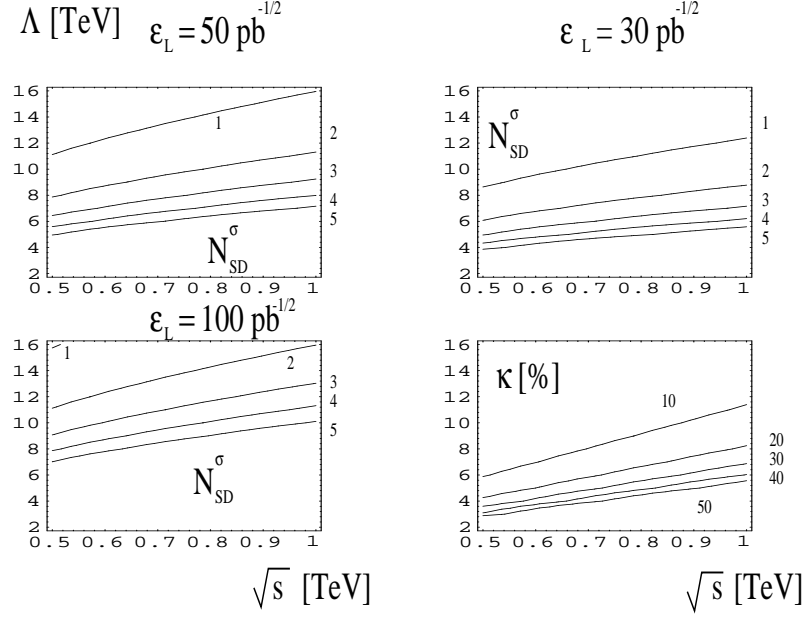


Figure 3: Contour plots for the statistical significance  $N_{SD}^\sigma$  for an observation of non-standard effects in the total cross section for  $\varepsilon_L = 30, 50, 100 \text{ pb}^{-1/2}$ . Contour plot for the relative correction  $\kappa$  to  $\sigma_{tot}$  is shown in the lower right plot.

is useful to define

$$\kappa \equiv \frac{\sigma_{tot} - \sigma_{tot}^{SM}}{\sigma_{tot}^{SM}} 100\% \quad \eta \equiv \frac{\mathcal{A}_{FB} - \mathcal{A}_{FB}^{SM}}{\mathcal{A}_{FB}^{SM}} 100\%. \quad (18)$$

In the Fig. 3 we present for  $\varepsilon_L = 30, 50, 100 \text{ pb}^{-1/2}$  contour plots for the  $N_{SD}^\sigma$  and also for  $\kappa$  in the  $\Lambda$ - $\sqrt{s}$  plane. Looking at  $N_{SD}^\sigma$  plots it is instructive to check whether for considered  $\Lambda$  and  $\sqrt{s}$  we are still in the perturbative region. It can be seen that for  $\varepsilon_L = 100 \text{ pb}^{-1/2}$  the non-standard effects can be observed even at the  $5\sigma$  level in the entire plane keeping  $\kappa$  below 10%. For  $\varepsilon_L = 50 \text{ pb}^{-1/2}$  and  $\sqrt{s} < .7 \text{ TeV}$  effects could be observable at  $3\sigma$  level, for larger  $\sqrt{s}$  corrections are greater than 10%. For  $\varepsilon_L = 30 \text{ pb}^{-1/2}$  only  $1\sigma$  would be available for the entire range of  $\sqrt{s}$ . These plots are designed to answer the question *what are the machine parameters necessary to test the nonstandard effects at a desired confidence level*.

The same attitude is assumed the Fig. 4, where we plot the statistical significance  $N_{SD}^{FB}$  for the forward-backward asymmetry  $\mathcal{A}_{FB}$ . We can see from the plots that here it is much less promising to observe an effect of non-standard physics. Even having  $\varepsilon_L = 100 \text{ pb}^{-1/2}$  one can only expect effects up to  $3\sigma$  level, staying below  $\eta = 10\%$ . It is easy to understand the reason for that, as we have already noticed that the four-Fermi operator effect the  $\frac{d\sigma}{d\cos\theta}$  mainly by rescaling it, therefore the  $\mathcal{A}_{FB}$  is not corrected that much as the total cross section  $\sigma_{tot}$  itself.

If one decided to keep  $S$  and  $T$  non-zero, than it could look attractive to consider polarized  $e^+e^-$  beams in order to suppress the SM contribution relative to non-standard scalar and/or tensor operator effects. However, as it has been checked by a direct calculation, with the same polarization for both  $e^+$  and  $e^-$  beams this strategy is not very promising since the relative corrections to the  $\sigma_{tot}$  and  $\mathcal{A}_{FB}$  grows faster with the po-



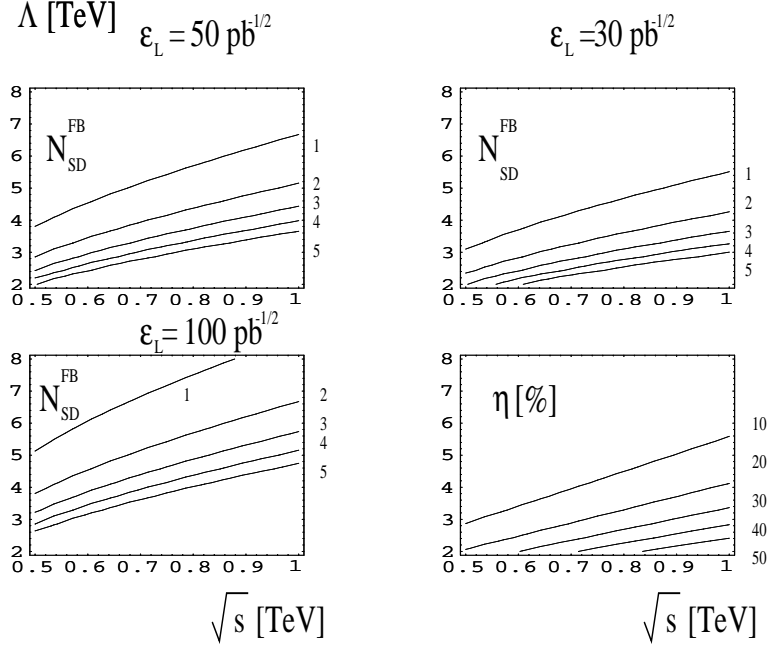


Figure 4: Contour plots for the statistical significance  $N_{SD}^{FB}$  for an observation of non-standard effects in the forward-backward asymmetry  $\epsilon_L = 30, 50, 100 \text{ pb}^{-1/2}$ . Contour plot for the relative correction  $\eta$  to  $\mathcal{A}_{FB}$  is shown in the lower right plot.

larization then the corresponding statistical significances and therefore we easily enter a region in the  $\Lambda$ - $\sqrt{s}$  plane where even for  $\epsilon_L = 100 \text{ pb}^{-1/2}$  tests at the level of  $5 \sigma$  would correspond to relative corrections close to 20 % which is already too large to trust our effective-Lagrangian tree-level computations.

## 5 Conclusions

We emphasize here that a consistent analysis of the process  $e^+e^- \rightarrow t\bar{t}$  can not be restricted to non-standard vertex corrections as it is often done in the existing literature. It has been shown that even considering only vector-type four-Fermi operators the prediction for the total cross section can be substantially modified allowing for test of non-standard physics of a scale of about 5 TeV. Ignoring theoretical prejudices and keeping  $S$  and  $T$  non-zero beyond the SM effects are even more pronounced. It has been checked that looking for non-standard physics in  $\sigma_{tot}$  and  $\mathcal{A}_{FB}$  it is more convenient to have a machine with larger  $\epsilon_L \equiv \sqrt{\epsilon_{tt}L}$  than one with polarized beams.

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